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National Ignition Campaign: Progress Update

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National Ignition Campaign: Progress Update

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Abstract: The National Ignition Campaign (NIC) is a comprehensive program to demonstrate a reliable and repeatable ignition platform and to develop the National Ignition Facility (NIF) as a user facility. This paper discusses the major progress achieved on NIC and future plans on the path to demonstrate ignition in the laboratory.

1. Introduction

The National Ignition Facility (NIF), located at Lawrence Livermore National Laboratory in Livermore, California, is the world's largest and most energetic laser facility for Inertial Confinement Fusion (ICF) research. NIF is the first laser system designed to obtain ignition and thermonuclear burn of deuterium–tritium-filled ICF capsules [1]. It is designed to compress and heat material, producing unique states of matter and unique radiation environments in the laboratory. These conditions are of interest for High Energy Density (HED) Science supporting the NIF missions in national security and fundamental science [2]. Ignition on NIF will also demonstrate the viability of inertial fusion for energy production. The NIF has been operational and conducting experiments since late in 2009. The combination of laser, target, and diagnostic capabilities available at NIF make it an unprecedented instrument for advancement of ICF and other areas of HED science. This paper will provide a progress update on the campaign designed to demonstrate fusion in the laboratory—the National Ignition Campaign.

2. The National Ignition Campaign

The NIC was formed in 2005 as a comprehensive program to provide all of the capabilities for performing ignition experiments and to develop the physics basis for ignition. The goal of the NIC program is to demonstrate a reliable and repeatable ignition platform and to develop NIF as a user facility for its multiple missions in national security, fundamental science and energy security.

NIC is a national effort that includes General Atomics, LLNL, Los Alamos National and Sandia National Laboratories, the University of Rochester Laboratory for Laser Energetics, and a number of collaborators including Lawrence Berkeley National Laboratory, the Massachusetts Institute of Technology, the U.K. Atomic Weapons Establishment, and the French Atomic Energy Commission [3]. The capabilities for performing ignition experiments include the diagnostics, targets, the target cryogenic system, phase plates and other optics, and personnel and environmental protection system.

The first experiments in the campaign to demonstrate ignition and gain used a 0.35- μm laser light with a central hot spot (CHS) target in an indirect-drive configuration (see Figure 1). CHS targets rely on simultaneous compression and ignition of the spherical

DT-filled capsule in an implosion. In the indirect-drive configuration, the capsule is placed inside a cylindrical cavity of high-Z metal (a hohlraum) [4]. Implosion pressure is provided by focusing the laser energy onto the interior walls of the hohlraum and converting it to x-rays. The small (few % of the total DT fuel mass), high-temperature central part of the imploded fuel provides the “spark,” which ignites the cold, high-density portion of the fuel. The NIF ignition experiments use a centimeter-scale Au/U hohlraum containing a 2-mm-diameter, thin-walled plastic or beryllium capsule filled with a mixture of deuterium and tritium (see Figure 2).



Fig. 1. The NIF with the major areas of the facility indicated and a cut-away showing the beam path.

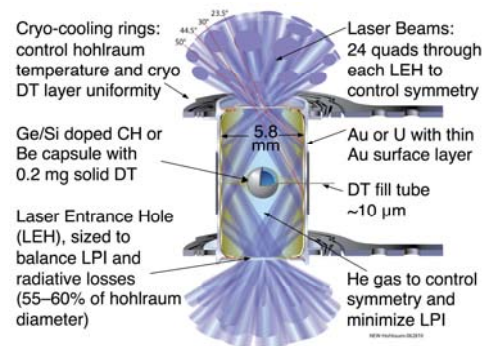


Fig. 2. The NIC indirect-drive ignition point design.

The NIC is structured into four phases. In the first “drive” phase, the empty hohlraum was tuned to produce the necessary radiation drive on the capsule as a function of time. In the second “capsule” phase, non-cryogenic and cryogenic capsules are used to adjust the hohlraum

symmetry, shock timing, velocity and mass ablated to produce the conditions in the imploding capsule required for ignition when a cryogenic fuel layer is incorporated. The third phase used layered cryogenic implosions with a mixture of T, H, and D in a ratio 74:24:2 to make the THD capsules hydrodynamic analogues to DT implosions. The low D content leaves the fuel unaffected by thermonuclear energy production, while the radiation and hydrodynamic transport resemble those of DT implosions up to the point at which DT implosions become perturbed by alpha particle production and deposition. The reduced yields from the THD shots allow the full diagnostic suite to be used and the required pre-burn temperature and fuel areal density (ρr) to be verified. The fourth and final phase is ignition implosions using cryogenic layered targets with a 50/50 DT mix.

The first two phases measured drive temperatures of 300 eV with backscatter of less than 15%, and radiation symmetry control was demonstrated to compressed cores to <10% [5]. Energy transfer between crossing laser beams is an important effect and can be controlled and has been used to modify the hohlraum environment. New models have been developed for the radiating plasma and are being used to refine the ignition target design [6, 7, 8, 9, 10]. The third phase began in September 2010, and THD capsule implosion results with 1.3 MJ demonstrated the hohlraum temperature of 300 eV and X-ray environment required for high convergence.

The fourth phase, or DT ignition campaign, began in September 2011, and experiments have been conducted with laser energies of up to 1.6 MJ, resulting in hot spot ion temperatures of 3.7 keV, a ρr of 1 g/cm² and neutron yields of $6\text{--}8 \times 10^{14}$. Progress in target performance is summarized in Figure 3, which shows the neutron yield vs. ρr . (Note that the ρr is not measured directly, but is inferred from the ratio of downscattered to primary 14-MeV neutrons.) The figure shows the results of the first three experimental campaigns. By increasing the implosion velocity (increasing laser input power to 450–500 TW), moving to lower adiabat implosions (modifying the detailed pulse shape and shock timing), and adjusting the drive symmetry, it is anticipated that the main fuel ρr will increase to the ignition levels of 2–2.5 g/cm², and fusion yields of 10 to 25 MJ are expected. This path to ignition is indicated on Figure 3.

3. Conclusions

NIF is operational and soon will demonstrate performance at its design goals of 1.8-MJ and 500-TW operations [11]. A full set of diagnostics has been commissioned for ignition experiments including radiation-hardened devices. The NIC results on ignition-scale targets show excellent performance with good energy coupling and good radiation symmetry control. Experiments are continuing to optimize the ignition target design for four major control variables for ignition: symmetry, fuel adiabat, shell velocity, and mix.

Ignition experiments are ongoing to improve performance and demonstrate alpha heating of the fuel. NIF scientists have also begun experiments supporting national security and fundamental science to establish NIF as a national user facility.

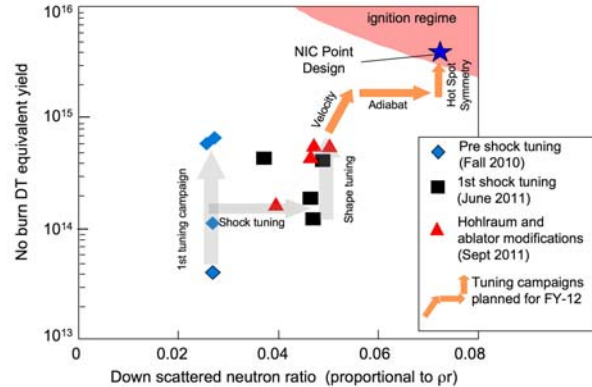


Fig. 3. Progress in the NIC tuning campaigns and anticipated path forward to ignition.

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